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Age-Related Within-Task Adaptations in Sequential Decision Making: Considering Cognitive and Motivational Factors

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Abstract

Many decisions require sequentially searching through the available alternatives. In these tasks, older adults have been shown to perform worse than younger adults, but the reasons why age differences occur are still unclear. In the present research, we tackle this question by investigating which strategies older and younger adults adopt and how these strategies relate to individual differences in cognitive (mental speed, working memory capacity) and motivational (need for cognitive closure) variables. To achieve this goal, we conducted two studies in which older and younger adults performed a computerized sequential choice task. Study 1 indicated that older adults changed their decision-making strategies throughout the task by reducing the number of options they considered. This change in strategy did not decrease performance because searching less allowed older adults to choose more promising options. In the second study we manipulated whether a long or short search was optimal. In the beginning older adults performed worse than younger adults independent of whether short or long search was adaptive. However, in the second half of the task we found age differences in performance when long search was required, but not when short search was required. In both studies whether or not older adults changed their strategy depended on their need for cognitive closure, suggesting that avoiding cognitive closure facilitates adaptive flexibility. Together, the two studies provide evidence for compensatory strategy adaptations among older adults completing sequential choice tasks.

Keywords: sequential choice, aging, need for cognitive closure, cognitive abilities

Introduction: Sequential Decision Making and Aging

Numerous decision problems that we encounter in everyday life are of a sequential nature. In these tasks, individual choice alternatives must be searched sequentially, one after the other. Furthermore, a decision to accept an option must be made immediately because it is usually not possible to return to an option that has been rejected. Consequently, the main challenge is to determine when to stop searching to maximize the probability of selecting the best alternative. Ending a search too early can mean not even seeing the best alternative, while searching too long carries the risk of rejecting the best available option. For instance, when searching for the cheapest airplane ticket, online prices often vary from day to day. If an individual buys the ticket on the first day, the price may be relatively high; thus, it may pay off to wait longer. However, waiting too long to buy a ticket can mean that prices rise, and the cheapest offer is missed.

Past research on sequential decision making has shown that people perform close to the optimal solution, although they often do not search enough (Seale & Rapoport, 1997, 2000; von Helversen & Mata, 2012; von Helversen, Wilke, Johnson, Schmid, & Klapp, 2011). Initial research on how the ability to solve sequential decision making problems changes with age indicated that older adults perform worse than younger adults because they search even less (von Helversen & Mata, 2012). The reasons why older adults search less are less clear. The study by von Helversen and Mata (2012) suggested that older adults search less persistently because they experience more positive affect. However, other studies on decision making have reported that older adults search for less information than younger adults, proposing a number of alternative explanations (e.g., Chen & Sun, 2003; Frey, Mata & Hertwig, 2015; Mata & Nunes, 2010; Mata, Schooler & Rieskamp, 2007; Mata, Pachur, von Helversen, Hertwig, Rieskamp, & Schooler, 2012; for a review see Mata & von Helversen, 2015; Mather, 2006). These explanations range from a decline in cognitive abilities, such as working memory capacity (Mather, 2006), processing speed (Salthouse, 1996), and further measures of fluid intelligence (Mata et al., 2007), to changes in motivational factors, such as a processing goals (Loeckenhoff & Carstensen, 2007) or increased motivational costs of cognitive effort (Hess, 2014). The goal of the present research is to investigate in more detail how older adults approach sequential decision making tasks and which role cognitive and motivational factors play in this process.

Age-Related Changes in Information Search

From laboratory experiments to real life settings, some effort is usually required to gain knowledge about possible choice options. The amount of information that is explored when making decisions varies among individuals. Past research suggests that older adults tend to search for less information than younger adults. Pachur, Mata, and Schooler (2009) found that older adults relied more frequently on recognition than younger adults and did not consider further information. Similarly, several studies of medical and consumer decisions have found that older adults request less information than younger adults (see review by Mather, 2006).

Both age-related decreases in cognitive resources and related motivational processes may contribute to the observed reduction in information search among older adults. Numerous studies demonstrate a gradual decrease in basic fluid cognitive abilities, such as processing speed and working memory capacity, across the adult life span (Engle, Sedek, von Hecker, & McIntosh, 2005; Salthouse, 2006, 2012; Sedek, Verhaeghen, & Martin, 2013; Sedek & von Hecker, 2004; Thornton & Dumke, 2005). Consequently, maintaining high levels of performance may tax older adults more strongly during cognitive tasks. In response, older adults may rely on compensatory processes to conserve resources (Baltes & Baltes, 1990; Hess 2000, 2014, 2015; Riediger, Li, & Lindenberger, 2006). One way to cope with limited cognitive resources is by simplifying their interactions with the environment, limiting both the quantity and complexity of information to which they attend. In this vein, older adults respond to complex decision-making tasks by relying on simpler decision strategies that require less information (Frey et al., 2015; Mata et al., 2007, 2012; Pachur et al., 2009).

Age-Related Adaptations to Limited Resources in Sequential Choice Tasks

How would age-related adaptations to limited resources play out in a sequential choices task? To investigate this question, we used a computer-based sequential choice task that was adapted from an earlier study (von Helversen & Mata, 2012). The sequential choice task imitates shopping online for various consumer products (e.g., fans or cameras). For each product, there are a number of price offers. The participants' goal is to select the cheapest offer by sequentially searching through the offers. Each trial (product) starts with a price offer. The participant then decides whether to accept that offer or to continue searching. If this offer is rejected, the next price offer for the product is presented, and the rejected price offer expires (i.e., the participants cannot go back to this offer at a later time point). Once a price offer is accepted, the product is purchased, and the participant moves on to the next product. If the participants do not accept any of the price offers, they must buy the product for the last price offer they receive.

In general, participants will not have precise knowledge about what constitutes a good price offer for the products. They can learn to assess the quality of an offer by searching through the offers and keeping track of their quality. This, however, will become more demanding with increasing search length because the more offers a participant experiences the more frequently he or she needs to decide whether to update or maintain which price offer currently holds the top position. In addition, it is not enough to keep the best offer seen so far in mind. To make good decisions a participant must also track the second, third, or fourth best option, because the probability that the best option has passed also increases with longer searches — which again increases the number of offers that must be updated or maintained.

Accordingly, given that cognitive resources are limited in older adults, older adults might end up settling for worse options than younger adults when the searching through many options is necessary for a good performance. But there are two different behavioral strategies that could lead to worse performances. First, older adults might attempt to search through the optimal number of options. However, if older individuals have difficulties in evaluating the quality of offers made later in the sequence, they might sometimes make mistakes and accept an option they should have rejected. In this case older adults would choose options that have a worse *relative rank* (i.e., the rank of an accepted price offer among the offers seen so far) than younger adults. Alternatively, older adults could search less and accept offers early in the sequence. Searching less will also lead to worse choices than searching through the optimal number of options, but it saves time and simplifies the decision process. Fewer options must be kept in mind, making it easier to recognize the options that are promising candidates — which, in turn compensates for the loss of quality caused by less searching.

In sum, one would expect that when older adults search as much as younger adults, they will perform worse because they select options with a worse relative rank. Alternatively, older adults may choose to simplify the decision by searching less but selecting options of a better relative rank. Furthermore, given that the task is new to them, older adults may start with searching through many options but adapt to a strategy with less searching over time — particularly when they realize over the course of the experiment that they can do so without costs to performance.

Whether a switch to a simpler strategy of searching less occurs may also depend on the participants' cognitive motivation. Here, the need for cognitive closure could be an important moderator (NFCC) (Kruglanski, 2004; Kruglanski & Webster, 1996). NFCC is described as a desire for a definite answer to a question to avoid uncertainty, confusion, or ambiguity (Kruglanski & Webster, 1996). Previous research demonstrated that NFCC is related to relying on simplified decision processes (Jaśko, Czernatowicz-Kukuczka, Kossowska, & Czarna, 2015; Kossowska, 2007; Kossowska, Orehek, & Kruglanski, 2010; for a recent review, see Roets, Kruglanski, Kossowska, Pierro, & Hong, 2015). Individuals with a strong NFCC are intolerant of confusion and uncertainty and are therefore inclined to make simplistic decisions. On the other hand, low-NFCC individuals are motivated to analyze situations in a systematic manner, consider alternative options, and make complex and flexible decisions (Kruglanski & Webster, 1996; Kossowska, 2007; Kossowska et al., 2010).

Aging usually increases scores on the NFCC scale; however even in old age variability in the need for cognitive closure can be large (Blanchard-Fields, Hertzog, Stein, & Pak, 2001; Kossowska, Hanusz, & Trejtowicz, 2012; Sedek, Kossowska, & Rydzewska, 2014). Recently, it has been shown that NFCC can be a moderator of age effects on decision-making. In particular, it seems that low need for cognitive closure could enable older adults to flexibly adapt to decision tasks. Czarnek, Kossowska and Sedek (2015) showed that older adults who scored high on the NFCC scale made more stereotypical inferences than younger adults, but not older adults who scored low on the NFCC scale. Similarly, Koscielniak, Rydzewska, and Sedek (2016) found that high NFCC scores were associated to age-related decreases in performance in the behavioral Balloon Analogue Risk Task (BART, Lejuez et al., 2002). These studies suggest that NFCC may also influence whether older adults adapt their behavior when searching in the sequential choice task. Accordingly, we expect that older participants that are low in NFCC will adapt their behavior more to the demands of the task, that is reduce search — when this is possible without a decrease in performance — but possibly also increase search when necessary. The rationale underlying this hypothesis is that low NFCC individuals, who are more tolerant of ambiguity, have also more processing flexibility (Czarnek et al., 2015; Kruglanski, Bélanger, Chen, Köpetz, Pierro, & Mannetti, 2012); therefore, they are able to find the best strategy, adjust it to the task and change it in different context. In contrary, high NFCC individuals usually choose the easy default option as the way to deal with the task and are also more rigid in their choices. Although low NFCC levels should lead to a more flexible adaptation to task demands in general, the influence of NFCC is likely to be stronger for older adults. In the sequential choice task older adults perform worse than younger adults (von Helversen & Mata, 2012) suggesting that the task is more cognitively demanding for older adults. Thus older adults have higher need to adapt their strategies to the task demands, which in turn should require low levels of NFCC. In contrast, young adults should be able to perform well on this task regardless of NFCC levels. We conducted two studies to investigate these questions. In the first study, we tested younger and older adults in a sequential choice task in which on average a medium search length was optimal. We measured individual differences in cognitive abilities and NFCC to investigate their contribution to performance and the behavioral strategies older adults adopted. In the second study, we tested whether age differences depend on the length of the search required by the task, by manipulating whether a long or short search was adaptive.

Study 1

In Study 1 we asked younger and older adults to repeatedly perform a sequential choice task in which they shopped for different consumer products. In addition, we measured fluid cognitive abilities (processing speed and working memory capacity), affect, and NFCC.

Method

Participants

One hundred and four people participated in the study, including 52 younger adults (35 women; mean age = 23.35 years, *SD* = 2.58) and 52 older adults (36 women; mean age = 68.21 years, *SD* = 3.49). The younger adults were students from different universities in

Warsaw (mean years of education = 15.63, *SD* = 2.10), with the exclusion of psychology students. Older adults were recruited from the Third Age Universities in Warsaw (mean years of education = 16.04, *SD* = 2.75). Participation in the study required between 1 and 2 hours. Participants received an average of 50 PLN (appr. 12 $) for their participation. The Ethics Committee of the Institute of Psychology at Jagiellonian University approved the study.

Materials

Measures of Cognitive Abilities, Affect and Motivation. We focused on processing speed and working memory capacity as measures of fluid cognitive abilities (e.g., Salthouse, 1996) by using the Digit Symbol Substitution Test (DSST) (a subtest of WAIS – R, Wechsler, 1981) and the computerized version of the Operation Span task (OSPAN) (Unsworth, Heitz, Schrock, & Engle, 2005), respectively. In the DSST, the participants receive a list of digit symbol pairs and must then fill in the corresponding symbol for as many digits as possible within 60 seconds. In the automated OSPAN task, the participants are asked to solve arithmetic problems and memorize letters at the same time. In a trial participants first solve an arithmetic problem such as "Does (7 x 2) + 3 = 17 ?" as quickly as possible by giving a "true" or "false" answer. After that they are asked to memorize a letter (e.g., L). After a series of math problems and letters have been presented, the participants are asked to recall the letters they saw during the set of trials. The number of problem/letter pairings in a trial set varies randomly between two and seven. Working memory capacity is measured based on the sum of letters in the trial sets in which all letters were correctly recalled.

In addition, the participants completed the Polish version (Kossowska et al., 2012) of the Need for Cognitive Closure – Short Scale (NFCC) (Kruglanski & Webster, 1996). The NFCC short scale consists of 12 items from four subscales: Desire for Predictability, Preference for Order and Structure, Discomfort with Ambiguity, and Close-mindedness. For each item participants are asked to rate how well it describes themselves on a 6-point scale from 1 (totally disagree) to 6 (totally agree). The reliability of the NFCC was satisfactory (Cronbach's alpha = .81).

Affect was measured with the Polish version (Fajkowska & Marszał-Wiśniewska, 2009) of the Positive and Negative Affect Schedule – Expanded Form (PANAS X; Watson & Clark, 1994), which consisted of 40 affective words, such as happy or lonely. The participants' task was to indicate the degree to which each word described their current mood on a scale from 1 (not at all) to 7 (very much).

Table 1 provides the mean values obtained for affect, cognitive, and motivation measures and one-way ANOVAs of age differences.

Sequential Decision Making Task. As mentioned above, the participants were asked to shop for various consumer products, such as fans, cameras, or blow dryers. Sixty different products with which younger and older adults would be similarly familiar on average were selected. The participants' task was to buy each product at the cheapest price possible. The presented prices were based on a normal distribution informed by the lowest and highest price offers found on the internet for each of the consumer products (the mean of the presented price offers was set at the midpoint between the highest and lowest offers, and 98% of all price offers fell between these values).

As the main behavioral measures in the sequential decision making task, we used performance, search, and (only for examining specific predictions) relative rank. Performance is defined as the average rank of the price offers selected by participants across trials. Accordingly, the better the performance (i.e., the cheaper the selected offers), the lower the average rank. For example, a performance of 5 means that this participant on average selected the fifth best offer across the trials. Search is defined as the average number of options rejected before making a decision. Relative rank is the average rank of the accepted price offer compared with the offers seen in the respective trial. A relative rank of one means that a participant on average selected a price offer that was better than all the offers he or she had seen so far for that product.

Procedure

At the beginning of the experiment, the participants completed the affect measure. The participants then read the instructions for the sequential choice task and performed a practice trial. In every trial the participants could search up to 40 price offers. The offers were presented sequentially in a random order. After an offer was presented, the participants had to decide whether to accept or reject that offer. Once rejected, the participants could not go back to the offer, and the next offer was displayed. If 39 offers were rejected, the participants were forced to select the last offer in the sequence. After selecting an offer (i.e., buying the product), the participants were presented with feedback regarding its rank and how many points they earned. At each point during the task, the participants were informed about the number of items and offers left in a sequence. There was no time limit for completing the task. The participants were paid according to the number of points they earned during the task, which was a function of the absolute rank of the chosen offers (i.e., the cheapest offer had a rank of 1, the second cheapest offer had a rank of 2, and so on). Participants were informed that they would earn 40 points when selecting the lowest price offer, 39 points when selecting the second cheapest offer, and so forth. The 60 products were displayed in a random order, but the order was the same for all participants. The 60 products were divided into 12 blocks with five items each. Each block of products was preceded by an indication of performance goals for the upcoming items and followed by an indication of performance satisfaction. Participants denoted their performance goals by indicating the average rank the offers they chose in the next five trials should reach so that they would be satisfied with their choices. For instance they could indicate they would be satisfied if on average they chose the 5-best offer. After each block, they also indicated their personal satisfaction with own performance on a scale from 1 (not satisfied at all) to 5 (very satisfied). Once the shopping task was completed, the participants were again asked to complete the affect questionnaire. Subsequently, the computerized OSPAN task, the digit-symbol substitution test, and the NFCC scale were administered.

Results

Cognitive Abilities, Affect, and Motivation

Descriptive statistics (see Table 1) showed that in comparison to younger adults, older adults performed substantially worse on the mental speed and working memory capacity measures and had significantly higher scores on the NFCC questionnaire. In contrast to the study performed by von Helversen & Mata (2012), no substantial age differences in positive mood were observed. Nevertheless, older adults reported less negative mood than younger adults at both measurement time points.

Age Differences in Sequential Decision Making

In the analysis of the sequential decision making task we focused on *performance*, assessing whether participants managed to choose cheap offers measured by the rank of the chosen offer, and *search*, the number of options participants considered before making a choice, as dependent variables. Given the structure of the task in which each individual completed 60 sequential decision making trials we used linear-mixed models (LMMs) to investigate whether older and younger adults differed in their sequential search behavior and how they adapted their behavior over time. Linear-mixed models can incorporate sources of correlation and variability between single sequential choice trials and have lower Type I and Type II errors than classical approaches (e.g. Baayen, Davidson, & Bates, 2008; Judd, Westfall & Kenny, 2012). Linear-mixed models were estimated using the lmer-function (*lme4* package, Bates, et al., 2014 and *lmerTest* package, Kuznetsova, Brockhoff, & Christensen, 2016) in R (version, 3.4.1; The R Foundation for Statistical Computing, 2017).

We build a separate linear-mixed model for each dependent variable with Age (Younger vs. Older Adults) and Trials (a centered continuous variable denoting the 60 trials) and the interaction of Age x Trials as fixed effects, and Participants and Products as random effects as well as random slopes for Trials. Random effects account for idiosyncratic variation due to individual differences between participants and products. The random slopes capture individual differences in change over time. We fit the linear-mixed models using the restricted maximum likelihood method (REML; Bates et al., 2014) and used the Satterthwaite approximations to estimate the degrees of freedom of the t-tests (*lmerTest* package).

Across all trials, older adults performed worse (i.e. selected trials with a higher rank, $M = 7.35$) than younger adults ($M = 5.64$). This was supported by the LMM analysis for performance that yielded only a significant main effect of Age, $b = 1.67$, $SE = 0.41$, t (102) = 4.11, $p < .001$, but no effect of Trials and no interaction (see Appendix A, Table A1 for the results of fixed effects). The age differences in performance are illustrated in Figure 1 (left panel) depicting the change of performance across trials[1].

In contrast, the analysis of search revealed no significant main effect of Age or Trial, but an interaction between Trial and Age $b = - 1.68$, $SE = 0.66$, t (102) = -2.54; $p < .02$ (see Appendix A, Table A1 for results of random and fixed effects). Whereas younger adults searched similarly long across the 60 trials, older adults reduced search over time (see Figure

[1] To depict how participants' behavior in the sequential decision-making evolves across trials we used simple moving averages (sometimes referred as running means), a popular computation and visualization technique in time series analysis (e.g., Oppenheim, Schafer, & Buck, 1999). We used moving averages with a window size of 10 and a step size of 5 because trial data was quite noisy due to strong effects of the specific sequential choice problems. To calculate a moving average, for instance for performance, first a participants' mean performance in the first trials is calculated with the number of trials included determined by window size (i.e. here trials 1 to 10 with window size 10), next the window is moved forward on the trial variable with the step size determining how far the window is moved (i.e. here the window is moved 5 trials to include trials 5 to 15) and again the mean performance is calculated. This procedure is continued until the end of the trials is reached. For all figures we calculated moving averages for each participant and then averaged across participants to show the group level data. Participant group means are drawn as separate lines with different colors (e.g. older, younger) and each line is accompanied with a 68% confidence interval.

2, right panel). In line with these findings, analyses testing for trials with each age group separately only showed a significant decline in search for older adults, $b = -1.86$, $SE = 0.52$, $t(51) = -3.55$, $p < .001$[2].

Relation of Individual Differences to Performance

Additionally, we tested whether participants' performance in the sequential decision making task was related to individual differences in motivation (Need for Cognitive Closure), cognition (OSPAN and DSST), and affect (Positive and Negative Affect at time point 1, before the decision task), as well as whether this relation differed between age groups. In order to do this, we correlated individual difference measures with participant's average performance in the sequential choice task for each age group separately. None of the correlations reached statistical significance. For details, see Table A2 in the Appendix.

In addition, we build separate linear-mixed models for each age group for performance as dependent variable, search and relative rank as fixed effects and Participants and Products as random effects as well as random slopes for Trials. Results showed that search and relative rank were significant and strong predictors of performance in both age groups. Older adults performed better the longer they searched ($b = -.25$, $SE = .001$, $t(3045.6) = -23.01$; $p < .001$) and the lower the relative rank of the chosen options ($b = 1.28$, $SE = .02$, $t(3072.5) = 51.43$; $p < .001$). For younger adults the results were quite similar: Performance increased with longer search ($b = -.18$, $SE = .008$, $t(3040) = -23.30$; $p < .001$) and lower relative rank of the accepted options ($b = 1.18$, $SE = .02$, $t(3066) = 62.48$; $p < .001$). These results suggest that on average participants tended to stop too early and could improve performance with longer search. In addition, also the relative rank of the accepted

[2] Because products were shown in the same order for all participants, models that do not contain an interaction of trial with a between subject variable (such as age) do not include random effects for products.

options mattered suggesting that whether the current option is better than the options seen so far can serve as an indicator of quality.

Sequential Decision Making and Need for Cognitive Closure: Within Task Adaptations among Older Adults

In line with the idea that older adults may rely on compensatory mechanisms we found that older adults reduced search over time without showing a drop in performance — even though in general more search was related to better performance. To understand these compensatory processes better and to investigate whether they depend on motivational predictors we analysed (1) whether changes in search were related to Need for Cognitive Closure (NFCC) and (2) whether the reduction in search was compensated by older adults choosing options with a better relative rank. To this goal we run two analyses. First, we added NFCC measure and its interaction with Age and Trial to the model on search. Secondly, we tested an additional model with the same predictors but Relative Rank as dependent variable.

The LMM analysis of search revealed a significant interaction between Trial, Age, and NFCC, $b = 3.45$, $SE = 1.25$, $t\ (100) = 2.75$; $p = .007$ (see Appendix A, Table A3 for results of fixed effects) in addition to the Age x Trial interaction reported above. This suggests that NFCC was differently related to search for older and younger adults. To disentangle this interaction, we conducted separate LMM analyses for both age groups. In the younger adults group there were no significant results (see Figure 2, panel A). In the older adults group the LMM analysis showed a main effect of Trial (older adults reduced search over trials), $b = -15.86$, $SE = 5.04$, $t\ (54.44) = -3.15$; $p = .003$, which was qualified by a significant interaction of NFCC with Trial, $b = 3.41$, $SE = 1.19$, $t\ (50) = 2.85$; $p = .006$. Further analyses examining older adults with low NFCC (M - $1/2\ SD$) and high NFCC (M + $1/2\ SD$) separately, showed that older adults with low NFCC reduced their search, $b = -4.65$, *SE* = 1.39, *t* (35.06) = 3.38; *p* = .002, whereas older adults with high NFCC scores did not (*p* = .59) see Figure 2 panel B.

The analyses of relative rank showed a similar pattern of results. As with the LMM analysis of search we found an interaction of Age by Trial as well as a three-way interaction of Trial, Age, and NFCC, *b* = 1.05, *SE* = .41, *t* (100) = 2.56; *p* = .02, see Table A3, in the Appendix A. Separate LMM analyses in both age groups showed no significant results for younger adults suggesting that the relative rank of the chosen options was stable across trials (see Figure 2, panel C). In contrast, for older adults the LMM analysis showed a main effect of Trial in line with the idea that older adults decreased relative rank together with search, *b* = -4.84, *SE* = 1.46, *t* (53.83) = -3.31; *p* = .002, which was qualified by a significant interaction of NFCC with Trial, *b* = 1.03, *SE* =.35, *t* (50) = 2.97; *p* = .005, see Figure 2 (panel D). Analyzes for older adults high and low in NFCC showed that only for older adults with low NFCC relative rank significantly decreased over trials, *b* = -1.25, *SE* = .46, *t* (45.14) = 2.73, *p* = .009, whereas older adults with high NFCC scores did not (*p* = .34)

Age Differences in Performance Goals and Satisfaction

The performance measure clearly indicated lower scores among older adults in comparison to younger adults. One possibility is that lower performance in older adults not only stems not from lower abilities but also a reduced motivation to perform well. Possibly older adults do not care as much as younger adults to obtain the best possible score (that is relatively low mean price) in the task, which in turn, could lead to older adults expending less effort and consequently performing worse than younger adults. This lack of motivation should lead to older adults reporting less ambitious performance goals and possibly also higher satisfaction with their performance relative to younger adults. To examine these questions we analyzed participants' performance goals (the estimated price rank to be achieved in the subsequent 5 trials with 12 measurements across the task) and satisfaction (with performance in the last 5 trials) and how they relate to performance. Therefore, we built separate linear-mixed models for each dependent variable with Age and Trial (as a centered continuous variable denoting the 12 measurement points) and the Age by Trial interaction as fixed effects. In addition, we included Performance (averaged across 5 trials) as a (fixed) covariate and random effects (including random slopes for Trials) for participants.

The linear-mixed model for performance goals did not yield any significant results (see Appendix A, Table A4 for results of fixed effects). On average performance goals of older adults (M = 6.47, SD = 5.53) were similar to performance goals of younger adults (M = 5.35, SD = 6.76). The linear-mixed model for satisfaction did also not result in any significant effects for age and the interaction of age with trials (see Appendix A, Table A4 for results of fixed effects). But a significant main effect of performance appeared, b = -0.09, SE = .006, t (1219) = -13.97, p < .001: the better the participants performed the more satisfied they were. On average older adults were similarly satisfied (M = 3.52, SD = .48) as younger adults (M = 3.76, SD = .67).

Discussion

Previous research has found that older adults perform worse than younger adults in sequential decision making tasks. Here, we aimed to extend this research to better understand the strategies on which older adults rely and to determine how those strategies relate to individual cognitive and motivational differences.

Similar to previous research, we found that older adults performed worse than younger adults (von Helversen & Mata, 2012). Further analysis suggested that the manner in which older adults approach the task changed across the task trials. In the first trials, older adults searched through a similar number of options as younger adults. However, the options that the older adults chose were not as good, as also indicated by a relatively high relative rank. This finding indicates that older adults might have had difficulties assessing the quality of options presented later in the sequence. Across the trials of the task, older adults changed their strategy by reducing search length but picking options with a better relative rank. Whether this switch occurred depended on the level of NFCC in older adults. Only older adults who were low in NFCC switched to a strategy of searching less over the course of the study, suggesting that having a flexible mind set enabled older adults to reduce search and rely on a simpler strategy.

Additionally, the results indicate that older adults had similar aspirations as younger adults. Older and younger adults also reported similar levels of satisfaction and satisfaction was in general strongly dependent on performance. The performance of participants in both age groups in sequential decision making tasks was neither related to cognitive abilities such as working memory span (OSPAN) or mental speed (DSST), nor to NFCC or current emotions (negative and positive affect as measured by PANAS-X).

A main result of this study was that older adults changed their behavior across the task to search less. This change in behavior is consistent with the idea that older adults adapt to the task because they have difficulties in correctly assessing the quality of options when searching through many options — possibly caused by limitations in cognitive resources. However, the study did not allow us to test directly whether tasks that require long searches are more difficult for older adults. To test this hypothesis and to investigate how older and younger adults adapt to different task requirements, we conducted a second study in which we manipulated within the sequential choice task whether searching through many or few options was adaptive.

In addition, we aimed to investigate the role of adaption processes over time. If older adults primarily benefit if they can achieve high performance with a short search, it should not matter whether the participants start with a task that requires a short search or whether these trials come later in the task. However, given that in Study 1, older adults started with a relatively long search and only learned over the task to search less, older adults may especially benefit from a task with a short search if it appears in the second half of the task.

Study 2

In Study 2, we adapted the sequential choice task to contain two subsets of trials that differed in terms of when the best options were presented. In one subset, the best options were mostly in the beginning of the sequence so that a short search was optimal. In the second subset, the best options were presented mostly at the end of the sequence so that a long search was optimal.

Method

Participants

One hundred twenty-eight people participated in the study, including 64 younger adults (41 women; mean age = 22.97 years, *SD* = 2.53) and 64 older adults (40 women; mean age = 69.37 years, *SD* = 3.22). The younger adults were students from different universities in Warsaw (mean years of education = 14.89, *SD* = 1.89), with the exclusion of psychology students. Older adults were recruited from the Third Age Universities in Warsaw (mean years of education = 14.52, *SD* = 2.91). Participation in the study took between 1 and 2 hours. Participants received on average 50 PLN (appr. 12 $) for their participation. We excluded 2 participants (one older participant and one younger participant) from the analysis because they performed close to chance level and 3 SDs below the mean in the *short search optimal* task. Table 2 reports descriptive statistics and age differences in cognitive abilities, NFCC, and measures of affect.

Design, Materials, & Procedure

Participants completed a sequential choice task that was similar to the task used in Study 1. The main difference from Study 1 was the distribution of price offers within the sequence. All participants worked on sixty trials in total: thirty trials in which the probability of the best price offer was higher at the beginning of the sequence (short search optimal) and thirty trials in which the probability of the best price offer was higher and at the end of the sequence (long search optimal). There were two between-participant conditions that varied the order of the two task types. In the first condition, the participants started with the task that required a short search and then continued with the task that required a long search (short-long condition). The opposite was true for the second condition (long-short condition). The participants were not informed about the different task types or aware that a change in the optimal search length could occur.

We created the two sub-tasks by changing the probability that the best offer would be presented in the first or last two-fifths of the offers. Specifically, in the 30 trials in which the best offer was in the beginning of the sequence, the best offer came before the 17th offer in 19 of the 30 trials, whereas in the 30 trials in which the best offer was at the end of the sequence, the best offer came after the 24th offer in 18 of the 30 trials. Moreover, to simplify the payoff scheme, the participants received points only for the five cheapest price offers: 40 points for the price offer ranked 1, 35 points for the offer ranked 2, 30 points for the offer ranked 3, and so on. We used the same measures that were used in Study 1 to characterize how the participants solved the task: performance, search and relative rank. Additionally, the participants completed all of the affect, cognitive, and motivation measures described in Study 1.

Results and Discussion

Sequential Decision Making: Performance and Search

To test our hypotheses, we built separate linear-mixed models for each dependent variable with Age (younger Adults, older Adults), Order (short-long, long-short), Task Phase (first part, second part) and their interactions as fixed effects, and Participants and Products as random effects, as well as random slopes for Task Phase and Trials (centered within Task Phase).

Performance. The analysis of performance yielded one main effect and two interaction effects: A main effect of Age, $b = 1.46$, $SE = 0.62$, $t\,(122) = 2.35$, $p = .02$, indicating worse performance among older adults ($M = 8.68$) in comparison to younger adults ($M = 6.85$). This main effect was qualified by two interactions: An interaction of Age with Task Phase, $b = 1.52$, $SE = 0.75$, $t\,(122) = 2.03$, $p = .05$, and a three-way interaction of Age x Order x Task Phase, $b = -2.93$, $SE = 1.06$, $t\,(122) = -2.76$, $p = .007$ (see Appendix A, Table A5 for results of fixed effects).

To disentangle this three-way interaction, we conducted separate linear-mixed models for each task phase separately (see Figure 3). In the first task phase older adults performed worse than younger adults independent of whether short or long search was optimal as indicated by an significant effect of Age, $b = 1.42$, $SE = 0.62$, $t(122) = 2.28$, $p = .02$, but no interaction, $b = 0.60$, $SE = 0.88$, $t(122)= 0.68$, $p = .50$. In the second phase, however, an interaction between Age and Order indicated that age differences in performance depended on whether long or short search was optimal, $b = -2.17$, $SE = 0.78$, $t(122) = -2.79$, $p = .006$. Follow-up tests showed large age differences when the long search conditions was second, $b = 2.94$, $SE = 0.60$, $t(61) = 4.91$, $p < .001$, whereas when the short search condition was second, no significant age differences appeared, $b = 0.76$, $SE = 0.49$, $t(61) = 1.54$, $p = .13$.

In sum, older adults still performed worse than younger adults, but age differences were strongly dependent on the task type and order. In the first task phase age differences occurred in the short and the long search tasks, however, in the second task phase age differences persisted (and even increased) in the long search task, but vanished in the short search task. This suggests that when the short search task followed the long search task this facilitated adaptation to the task for older adults.

Search. The linear-mixed model of search yielded one main effect and two interaction effects with age group. There was a main effect of Order, $b = 6.08$, $SE = 1.71$, $t(166.39) = 3.56$, $p < .001$, with overall less search in the short-long condition than in the long-short condition. This main effect was qualified by three interactions: an interaction of Age x Task Phase, $b = -3.07$, $SE = 0.94$, $t(122) = -3.28$, $p = .002$, an Order x Task Phase interaction, $b = -5.91$, $SE = 2.38$, $t(73.75) = -2.48$, $p = .02$, and an Age x Order x Task Phase interaction, $b = 3.18$, $SE = 1.32$, $t(122) = 2.40$, $p = .02$ (see Appendix A, Table A5 for results of fixed effects).

To disentangle the three-way interaction, we again ran separate linear-mixed models in the two task phases (see Figure 4). In the first task phase we found a large effect of Order, $b = 6.61$, SE = 1.88, $t(150.14) = 3.52$, $p <.001$, but no difference between age groups, $b = -0.37$, $SE = 1.33$, $t(122) = -0.28$, $p = .78$, and no interaction of Age and Order, ($p = .75$) suggesting that both age groups adjusted to the task requirements and searched more in the long task than in the short task. In contrast, in the second task phase, the analysis revealed a main effect of Age, $b = -2.97$, $SE =1.00$, $t(122) = -2.98$, $p = .004$, and an interaction of Age and Order, $b = 3.76$, $SE =1.41$, $t(122)= 2.67$, $p = .009$. When the long task was second, older adults searched significantly less than younger adults, $b = -3.55$, $SE = 0.97$, $t(61) = -3.65$, $p < .001$. Whereas, when the short task was second, both age groups searched similar amounts, $b =1.15$, $SE = 0.98$, $t(61)=1.18$, $p = .24$.

In sum, older and younger adults were able to adjust their search to the task structure in the first part of the task. In the second task phase strong age differences appeared when long search was optimal with older adults searching much less than younger adults, whereas no age differences occurred when short search was optimal and both younger and older adults reduced search — reflecting the age differences found in performance.

Within Task Adaptations in Older and Younger Adults

In the analyses, so far we had focused on adaptations on the task level. In a next step we aimed to investigate adaptations within each task. To assess how older and younger adults adapted within each task phase we tested for linear and quadratic effects of Trials (fixed effects) for each Age group for each of the four combinations of Order and Task Phase separately. As random effects we included intercepts for participants and random slopes for trials. Because these are exploratory analyses and we conducted multiple tests (32), we adjusted the alpha level for significance according to a Bonferroni correction to $p < .002$. Here, we focus on the significant effects but a full summary of the results can be found in Table A6 in the Appendix.

As illustrated in Figure 4, younger adults decreased search linearly when short search was adaptive independent of whether this task was in the first or second task phase. When long search was adaptive we did not find a significance linear decrease or increase. However, when long search was necessary in the second task phase, the analysis indicated a quadratic effect on search, suggesting that younger adults first somewhat decreased and then increased search again. Descriptively changes in performance corresponded to the changes in search, with a reduction in search in the short task increasing performance, but reductions in search in the long task decreasing performance. However, these changes did not reach the Bonferroni corrected level of significance except when short search was adaptive in the second task phase (see also Figure 3).

For older adults we also found a linear decrease in search over trials when the short search task was in the first task phase, but not when the short search was in the second phase. In addition, we also found a linear increase in search when the long search task appeared in the second task phase. Descriptively, performance slightly increased in the two short search tasks over time, but these changes also did not reach the Bonferroni corrected level of significance.

In sum, both younger and older adults showed within task changes in correspondence to the task structure. When short search was adaptive they decreased search, whereas when long search was adaptive both age groups either increased search or kept search at a high level across trials.

The Role of NFCC for Task Adaptations in Older Adults

In the first study we found that NFCC moderated whether older adults reduced search across the task. To investigate whether NFCC was related to changes in search in the second Study we run LMM analyses on search including Task Phase and Trials (within each task phase) as fixed effects, random intercepts for participants and products, as well as random slopes for Trials and Task Phase, separately for the two Order conditions and for each Age group. The analyses revealed no effect of NFCC for younger adults. We found, however, that NFCC was related to how older adults adapted their search across trials within each task phase in both order conditions. The results are illustrated in Figure 5.

In the long-short order condition, NFCC interacted with Trial, b = -5.05, SE = 2.35, t(57.4) = -2.15, p = .04. To follow up on this interaction we conducted separate analyses for participants low and high in NFCC (Mean -/+ ½ SD) in each task phase. Although none of the changes reached significance, descriptively older adults low in NFCC increased search in the long phase, b = 4.29, SE = 2.64, t(15) = 1.63, p = .124, and decreased search in the short phase, b = -1.46, SE = 1.81, t(434.5) = -0.80, p = .423, whereas participants with a high NFCC tended to decrease search in both phases, long: b = -2.47, SE = 2.48, t(18.28) = -1.00, p = .33, short: b = -0.27, SE = 3.13, t(8.16) = -0.9, p = .934 (see Figure 5, right panel).

In the short-long order condition, we again found an interaction of NFCC with Trial, b = 6.48, SE= 2.26, t (104) = 2.87, p = .005. In addition, we found a three-way interaction of

NFCC with Trial and Task Phase, b = -7.11, SE = 3.11, t (1709) = -2.28, p = .023, suggesting that NFCC moderated how well participants adapted to each task phase. Follow up analyses showed that participants with low NFCC significantly reduced search in the short task, b = -8.16, SE = 2.62, t(28.19) = -3.12, p = .004, whereas participants with a high NFCC did not, b = -2.64, SE = 2.34, t(13.52) = -1.13, p = .28. In addition, participants with a low NFCC increased search in the long search task, b = 4.57, SE = 1.68, t(202) = 2.72, p = .007, more than participants with a high NFCC, b = 3.74, SE = 1.69, t(12) = 2.21, p = .05 (See Figure 5 left panel).[3]

These results suggest that NFCC plays an important role in the adaptation of search in older adults and extend our findings from the first study. Notably, NFCC influenced within task adaptations but we did not find an effect of NFCC on the general adaptations to the task phase. This suggests that all participants adapted to the manipulation of the task structure but NFCC moderated how strongly participants responded to them.

The Role of Cognitive Abilities, Affect and NFCC for Performance

Lastly, we analysed whether working memory capacity (Ospan) and processing speed (digit symbol) influenced performance in each age group and how these depended on the task type.

To this goal we correlated the cognitive abilities measures with mean performance scores in the long and the short search task for each age group separately. For younger adults, both working memory capacity and processing speed correlated significantly with performance in the long search tasks, processing speed: r = -.26, p = .038, Ospan: r = -.41, p = .001 (see Figure 6 panels B and D). These correlations were less strong in the short search tasks, processing speed: r = -.15, p = .254; Ospan: r = -.25, p = .051 (see Figure 6, panels A

[3] Coefficients were calulated at ½ SD +/- the mean. Some models in the follow-up analyses did not converge taking random slopes for trials into account. In this case we estimated them without the random slopes.

and C).[4] In the older age group, cognitive abilities did not correlate with performance in the long search task (*p*s > .65). In the short search task, processing speed was correlated with performance, $r = -.29$, $p = .023$, but not working memory capacity, $r = .03$, $p = .802$, see Figure 6.

NFCC was not related to performance in the long and the short search task in younger or older adults (all *p*s > .22). In younger adults positive mood at time point 1 correlated with performance in the long search task, $r = .25$, $p = .045$ indicating worse performance with higher positive mood, but it did not correlate significantly with search length. In older adults neither positive nor negative affect was related to performance or search.

Performance Goals and Satisfaction

Similarly, as in Study 1 we examined the questions about possible age differences in performance goals and satisfaction and the relation of those variables with performance. To examine these questions, we again analyzed the reported scores (12 measurements across the task) for performance goals (the estimated price rank to be achieved in the subsequent 5 trials) and satisfaction (with performance in the last 5 trials) and how they relate to performance by building separate linear-mixed models for each dependent variable with Age (younger Adults, older Adults), Order (short-long, long-short), Task Phase (first part, second part) and their interactions as fixed effects. In addition, we included Performance (average across 5 trials) as a (fixed) covariate and random effects (including random slopes for Trials) for participants.

The linear-mixed model for performance goals did not yield any significant results (see Appendix A, Table A7 for results of fixed effects). On average performance goals of older adults ($M = 4.29$, $SD = 3.83$) were similar to performance goals of younger adults ($M =$

[4] Two younger participants had Ospan scores of zero. Excluding these participants does not change the pattern of results. However, the correlation of Ospan with performance in the short task is much lower, $r(61) = -.08$, $p = .568$.

3.86, *SD* = 4.75). The linear-mixed model for satisfaction did not yield any significant effects for Age and the interaction of Age with Trials (see Appendix A, Table A7 for results of fixed effects). But again, a significant main effect of performance appeared, $b = -0.03$, $SE = .002$, $t(1416) = -9.56$, $p < .001$: The better the level of performance the more satisfied were the participants. On average older adults were similarly satisfied ($M = 3.13$, $SD = .78$) as younger adults ($M = 3.11$, SD = .53).

General Discussion

The ability to make good choices when sequentially searching through options is required in many tasks in daily life, ranging from choosing a parking spot to selecting the best price offer for air plane tickets and consumer products or searching for an apartment. In the current research, we aimed to understand how older adults approach these tasks and to determine the role of cognitive and motivational variables in understanding age-related differences in performance. To achieve this goal, we examined how older adults differ from younger adults in their ability to adapt their strategies within a sequential decision-making task in which the best offer was equally likely to appear at any position of the sequence (Study 1) and when the optimal length of search changed within the task (Study 2). In addition, we measured affect, fluid cognitive abilities (processing speed and working memory capacity), and need for cognitive closure in both age groups.

Age differences in performance and decision strategies for sequential decision making

Consistent with previous research, we found that older adults selected worse options than younger adults (von Helversen & Mata, 2012). Extending these findings, we found that although older adults performance did not change much across the task they changed their search strategy. In the beginning of the task, older adults searched as long as young adults but chose worse offers — possibly because correctly assessing the relative quality of an option is more challenging when more options are considered. But, over the course of the task, many older adults simplified the task by reducing how long they searched. In addition to saving resources and time, this strategy helped older adults settle for options that were similar in relative rank to those chosen by younger adults, resulting in a similar average performance as the long search strategy. These results resonate with other research in decision-making, which suggested that older adults switch to strategies that require limited search in complex decision-making tasks (e.g., Mata et al., 2007; Pachur et al., 2009). In addition, this finding is consistent with the idea that searching for less information may be adaptive if it enables fewer errors in the decision-making process and can lead to relatively small losses in decision quality (Mata & Nunes, 2010; Mata et al., 2012).

The idea that older adults adapted their decision strategy in response to the task structure was supported by Study 2, in which we experimentally manipulated whether a long or short search was necessary to perform well in the task. In the beginning older adults performed worse than younger adults independent of whether short or long search was adaptive. However, in the second half of the task we only found age differences in performance when a long search was required, but not when short search was required suggesting that older adults had more problems when a task required longer search. This relates to research suggesting that age differences increase with task difficulty (e.g., Frey et al., 2015; Mata, von Helversen, & Rieskamp, 2010). Furthermore, the results suggests that in addition to the effect of task difficulty, learning and motivational effects play a role. Older and younger participants may be motivated to search more at the beginning of the task to learn about the task. However, older adults might then switch to a more resource saving strategy due to the larger cognitive costs of exploration. In this vein, when a long search was required in the second half of the task, older adults searched much less than younger adults, whereas the age groups did not differ in the length of search when the long search task was presented at the beginning of the task.

Cognitive Abilities, Motivation and Affect as Predictors of Performance and Search

In Study 1 we did not find any relation between measures of cognitive abilities and performance and search. However, in Study 2 performance in the sequential choice tasks was related to both working memory capacity and processing speed. In particular, in the long search tasks choosing the right options can be difficult because it requires keeping the quality of previously viewed options in mind. Consistent with this idea, we found that for young adults performance was related to cognitive abilities more strongly in the long search task than the short search task. Notably, this finding did not generalize to older adults. For older adults, we only found a correlation of processing speed with performance in the short search task, whereas working memory capacity was not related to performance in the short or long task. One explanation for this pattern of results is that the long task was so taxing that the influence of fluid abilities on performance can only be detected if a certain level of performance is reached. Here, further research on the relation of cognitive abilities to performance in these tasks in older adults is necessary.

In contrast to the finding reported by von Helversen and Mata (2012), we found no relation between affect and search in older and younger adults. One reason for the diverging results could be that overall levels of positive affect were rather low in the current samples, and older adults did not experience higher levels of positive affect than younger adults. In the second study lower performance in the long search task was related to higher positive affect in younger adults, which is in line with the results by von Helversen and Mata. However, we did not find a corresponding negative correlation of positive affect with search.

With respect to the role of motivational variables, we found that older and younger adults did not differ in the performance goals they reported during the task or their average level of satisfaction. Nevertheless, motivational variables such as the need for cognitive closure seem to be an important moderator of adaptive processes. In the first study only older adults who avoided cognitive closure adapted to the demands of the sequential choice task and decreased both search and the relative rank in the second part of the task. In the second study we found that although all older adults adapted to the manipulated changes in the tasks, the degree to which older adults changed their search within a task phase was again moderated by NFCC. Older participants with low NFCC scores reduced search more strongly when short search was adaptive and increased search more strongly when long search was adaptive than older participants with high NFCC scores. These results indicate that avoiding cognitive closure might be an important factor in enabling adaptive compensatory mechanisms in older adults. They are consistent with previous findings indicating that avoiding cognitive closure facilitates non-schematic and efficient performance (Czarnek et al., 2015; Koscielniak, et al., 2016; Kruglanski et al., 2010; Roets et al., 2015). Notably, we did not find an effect of NFCC on younger adults performance or search. This suggests that NFCC may only play a role when a task is perceived as demanding and requires compensatory adaptations as in the sample of older adults.

Future Research and Limitations

The current research suggested that older adults preferred and performed relatively well in tasks in which they could switch to a strategy that required a short search after a period of exploration. Given that exploration strategies may be similar across different task domains (e.g., Hills, Todd & Goldstone, 2010; Mata & von Helversen, 2015), it would be interesting to determine whether similar task adaptations can be observed in other tasks that require exploration, such as when participants learn from experience (e.g., Hess, 2015; Mata et al., 2010). Another important issue for future research is to demonstrate further evidence and limiting conditions in decision-making tasks in which avoiding cognitive closure could be considered to be a compensatory mechanism for age-related limitations in cognitive abilities among older adults.

Possible limitations of the current research include cohort effects and limitations caused by the nature of the design. Although we attempted to find consumer products that would be familiar for both older and younger adults, younger adults are probably more familiar with online purchases than older adults — which could have facilitated their assessments of the quality of the price offers. Therefore, and because cross-sectional designs (particularly designs with extreme age groups) only allow limited conclusions about the correlations of age-related changes with different measures (e.g., Lindenberger & Pötter, 1998; Maxwell & Cole, 2007), future studies should investigate changes in decision-making abilities in longitudinal designs.

Furthermore, age differences in performance and search in sequential decision-making may be associated with further age-related changes that we did not measure in this study such as the propensity to take risks. In general, self-reported risk taking decreases over the adult age span in the majority of risk taking domains (Josef, Richter, Samanez-Larkin, Wagner, Hertwig & Mata, 2016, but see Mata, Josef, Samanez-Larkin, & Hertwig, 2011). In sequential decision making tasks longer search may be perceived as riskier as it involves giving up a certain option for an uncertain, but possibly better, option in the future. In this vein, age-related reductions in search may stem from age-related increases in risk aversion. Future research studying the relation of risk preferences to sequential decision-making in young and older adult is necessary to clarify this question and estimate the contribution of risk preferences on sequential decision-making.

Conclusions

Consistent with previous research in other areas of decision-making, we found that older adults changed decision-making strategies within a sequential decision-making task — possibly to compensate for increased cognitive demands related to limited cognitive resources. Although older adults searched similarly at the beginning of the task, they switched to a resource-saving strategy over the course of the task, particularly when this change could be made without a loss of performance. When this strategy was reflected in the task structure, age differences disappeared in the task that required a short search. This finding suggests that the negative effects of age on decision performance can be avoided by changing the structure of decision-making tasks. Accordingly, in tasks in which good options are likely to be encountered in the beginning of the task (for instance, when searching for information on the internet), older adults may perform well — particularly if they have the chance to familiarize themselves with the task.

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Table 1

Study 1: Participants' Characteristics

Measures	Younger Adults (N = 52; 35F)		Older Adults (N = 52; 36F)		Statistical test		
	M	*SD*	*M*	*SD*	*F*	*P*	η^2
Cognitive measures							
DSST	42.29	6.95	28.27	5.02	139.11	.001	.577
OSPAN	38.77	18.25	18.77	15.13	37.00	.001	.266
Motivational and affective measures							
NFCC	3.45	.76	4.11	0.42	30.19	.001	.228
Positive affect 1	3.26	0.71	3.23	0.61	0.04	.85	.000
Negative affect 1	1.82	0.84	1.51	0.65	4.45	.04	.042
Positive affect 2	3.37	0.80	3.14	0.75	2.35	.13	.023
Negative affect 2	1.48	0.70	1.24	0.36	4.80	.03	.045

Note. DSST = Wechsler's Digit Symbol Substitution Test; OSPAN = Operation Span of Working Memory; NFCC = Need for Cognitive Closure; affect 1 and affect 2 refers to measurement time points 1 (before the decision task) and 2 (after the decision task).

Table 2

Study 2: Participants' Characteristics

Measures	Younger Adults (N = 63)		Older Adults (N = 63)		Statistical test		
	M	*SD*	*M*	*SD*	*F*	*P*	η^2
Cognitive measures							
DSST	43.33	8.00	26.37	5.77	186.55	.001	.601
OSPAN	36.68	15.23	18.56	15.55	43.68	.001	.261
Motivational and affective measures							
NFCC	3.69	0.57	4.02	0.54	11.09	.001	.082
Positive affect 1	3.20	0.58	3.26	0.62	0.30	.59	.002
Negative affect 1	1.90	0.81	1.56	0.48	8.04	.005	.061
Positive affect 2	3.26	0.69	3.24	0.66	0.02	.89	.000
Negative affect 2	1.65	0.76	1.41	0.48	4.70	.03	.037

Note. OSPAN = Operation Span of Working Memory; DSST = Wechsler's Digit Symbol Substitution Test; NFCC = Need for Cognitive Closure; Positive and Negative Affect = PANAS-X scores; affect 1 and affect 2 refers to measurement time points 1 (before the decision task) and 2 (after the decision task).

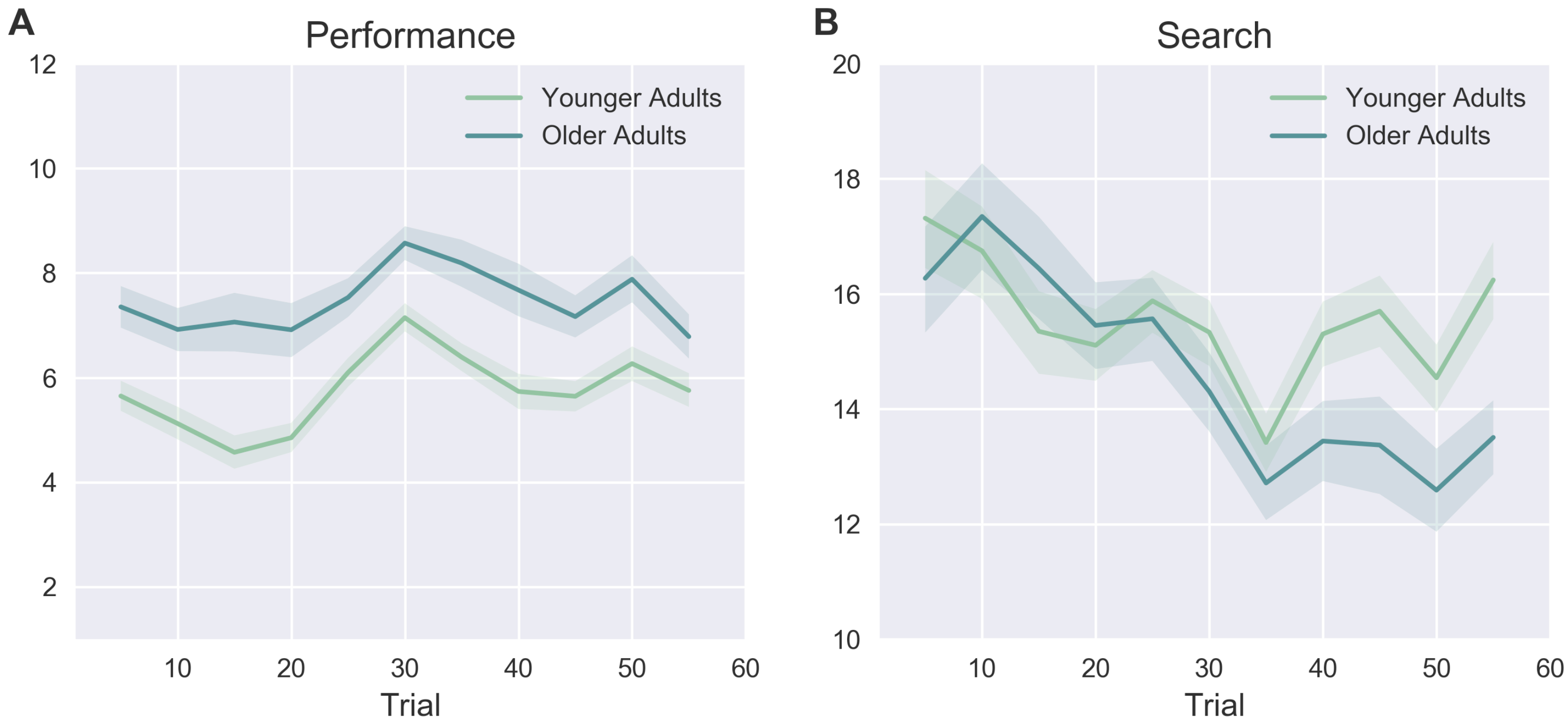

Figure 1. Performance (left Panel A) and Search (right Panel B) as a function of age group and consecutive trials in Study 1. Values of dependent variables are obtained by calculating moving averages with the window size of 10 trials and window step of 5 trials. Shadowed 68% Confidence Intervals represent one standard error below and above the means.

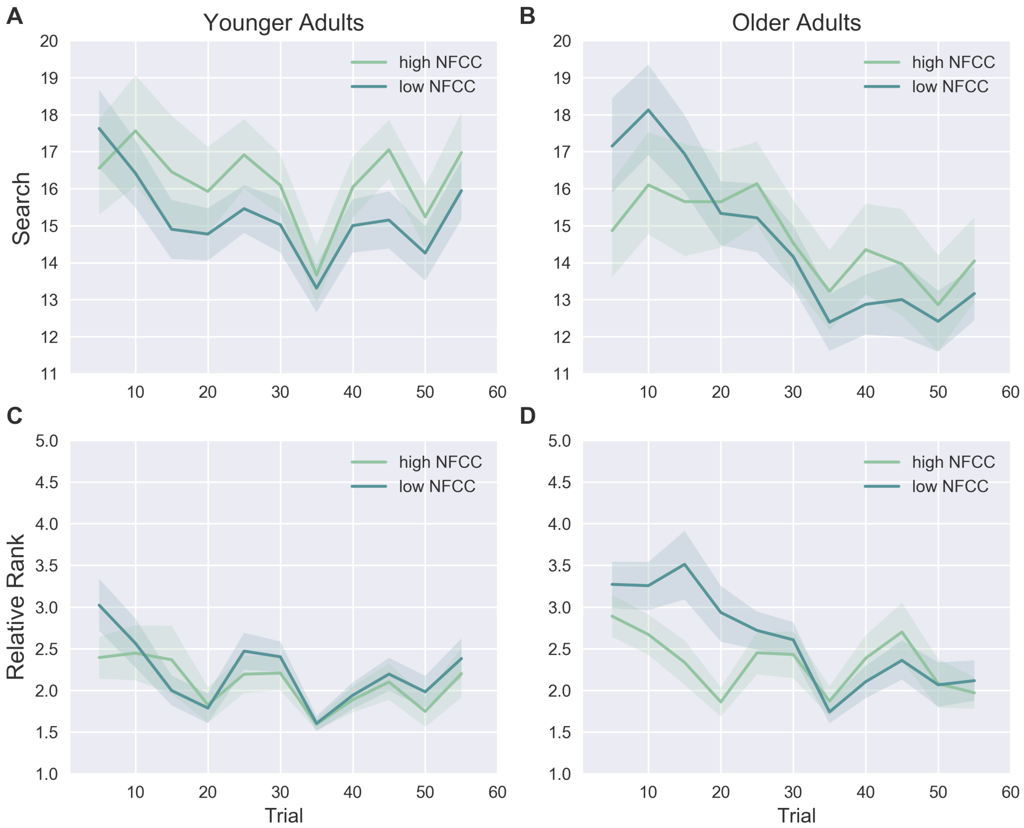

Figure 2. Search (Top Panels A and B) and Relative Rank (Down Panels C and D) as a function of age group, NFCC (need for cognitive Closure) and consecutive trials in Study 1. Values of dependent variables are obtained by calculating moving averages with the window size of 10 trials and window step of 5 trials. Shadowed 68% Confidence Intervals represent one standard error below and above the means. High NFCC refers to *M* + ½ *SD* within age groups, low NFCC refers to *M* – ½ *SD* within age groups.

Figure 3. Performance as a function of age group, order (left Panel A: condition long – short; right Panel B: condition short - long), and consecutive trials in Study 2. Values of dependent variables are obtained by calculating moving averages with the window size of 10 trials and window step of 5 trials. Shadowed 68% Confidence Intervals represent one standard error below and above the means.

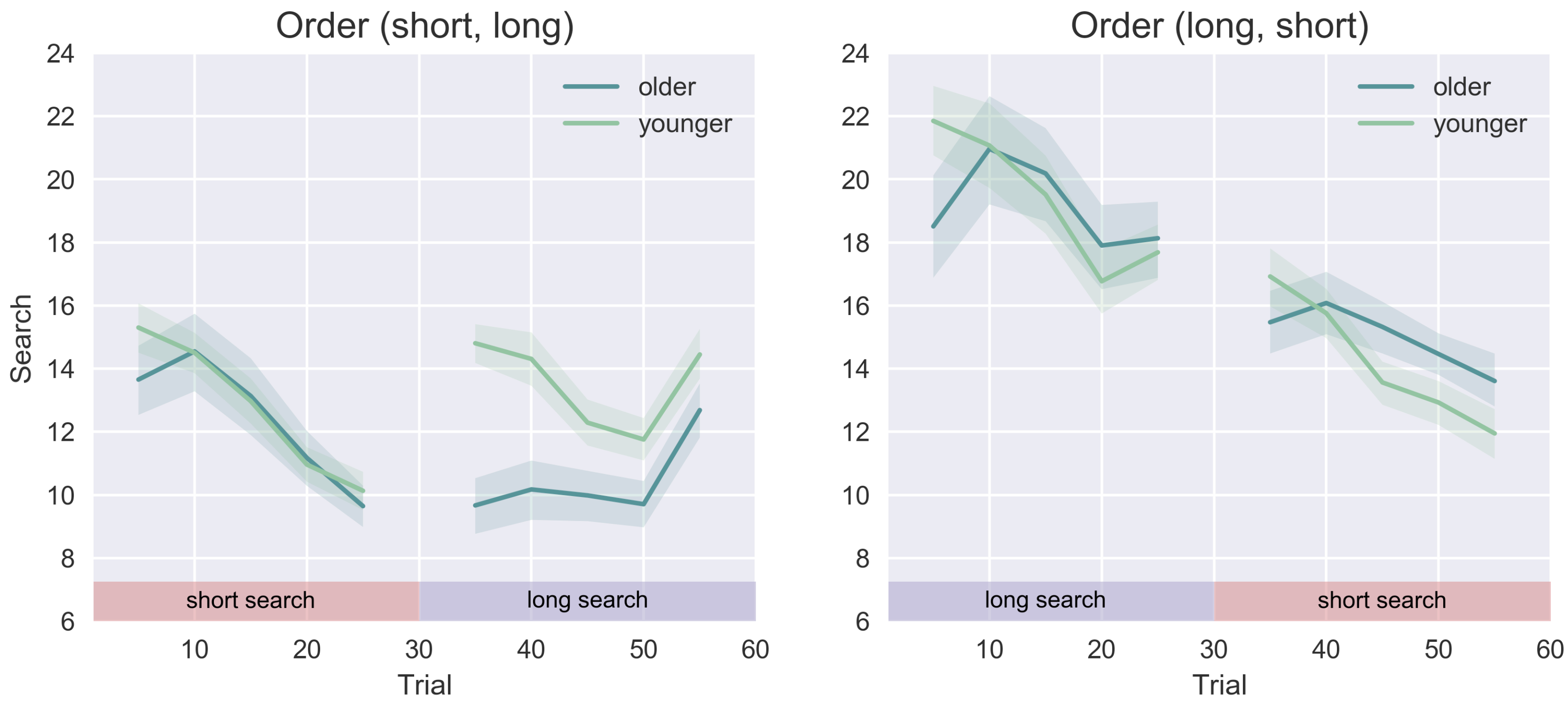

Figure 4. Search as a function of age group, order (left Panel A: condition long – short; right Panel B: condition short - long), and consecutive trials in Study 2. Values of dependent variables are obtained by calculating moving averages with the window size of 10 trials and window step of 5 trials. Shadowed 68% Confidence Intervals represent one standard error below and above the means.

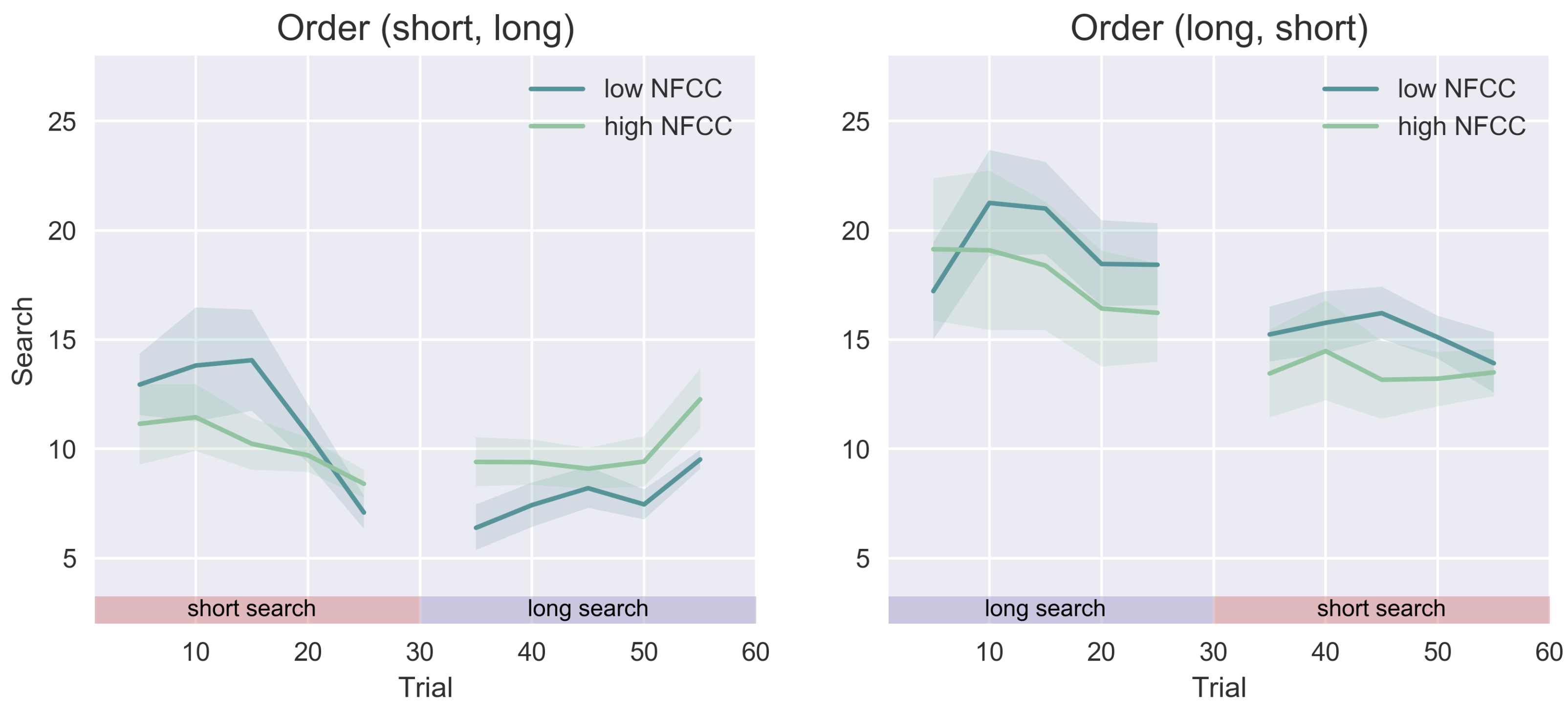

Figure 5. Search in the short-long condition (left panel) and the long-short condition (right panel) for older adults as a function of NFCC (need for cognitive Closure) and consecutive trials in Study 2. Values of dependent variables are obtained by calculating moving averages with the window size of 10 trials and window step of 5 trials. Shadowed 68% Confidence Intervals represent one standard error below and above the means. High NFCC refers to *M* + ½ *SD* within older adults, low NFCC refers to *M* – ½ *SD* within older adults.

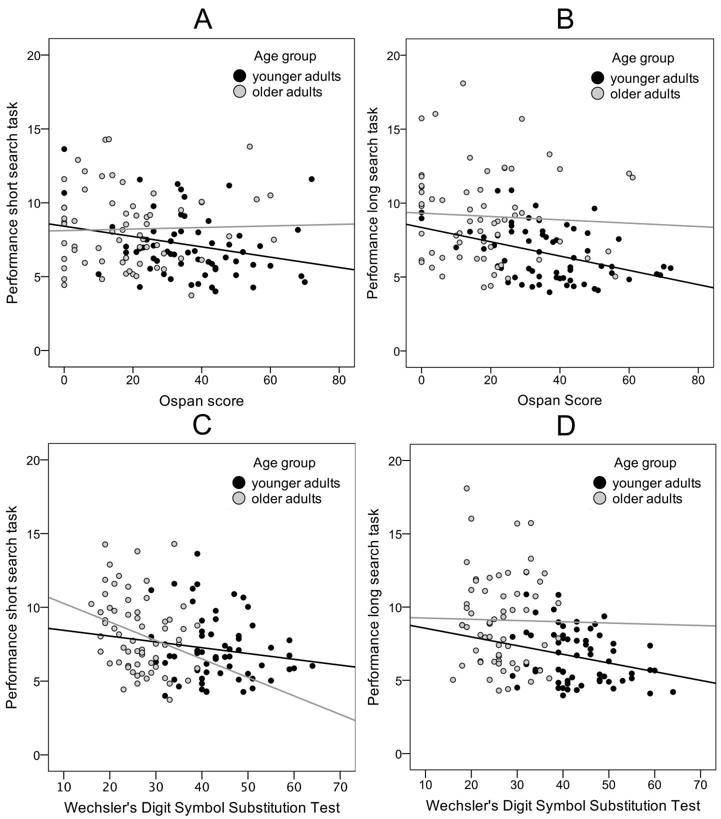

Figure 6. Scatterplots of performance in the short (panels A and C) and long search task (panels B and D) and operation span (Ospan, panels A and B) and digit symbol substitution scores (panels C and D) for younger (black markers) and older adults (grey markers). Black lines denote regression lines for the young adults, grey lines for the older adults.

Appendix A

Table A1
Study 1: Results of linear-mixed model for performance and search as a function of age and trials

	Performance				Search			
	b	SE	df	t	b	SE	df	t
(Intercept)	5.68	0.40	137.61	14.26***	15.65	0.88	131.21	17.85
Age	1.67	0.41	102.00	4.11***	- 0.98	0.82	102.00	-1.18
Trials	0.34	0.52	69.29	0.65	- 0.18	1.23	73.71	-0.15
Age:Trials	- 0.53	0.29	102.00	- 1.79	- 1.68	0.66	102.00	-2.54*

Note. Regression coefficient (*b*), standard error (*SE*), t value (*t*), and degrees of freedom (df) of fixed effects; $N = 104$; * $p < .05$, *** $p < .001$.

Table A2

Study 1: Correlations of average performance with individual difference measures of cognitive abilities, affect, and need for cognitive closure (NFCC) for young and older adults separately

	Younger Adults (N =52)		Older Adults (N = 52)	
Measures	*r*	*p-value*	*r*	*p-value*
Ospan	-.05	.70	-.20	.17
DSST	.07	.64	-.08	.58
Positive Affect 1	-.15	.29	.09	.53
Negative Affect 1	.05	.75	.03	.83
NFCC	-.24	.08	-.14	.33

Note: OSPAN = Operation Span of Working Memory; DSST = Wechsler's Digit Symbol Substitution Test; NFCC = Need for Cognitive Closure; Positive and Negative Affect = PANAS-X scores; affect 1 and affect 2 refers to measurement time points 1 (before the decision task) and 2 (after the decision task).

Table A3

Study 1: Results of linear-mixed model for search and relative rank as a function of age, trials, and NFCC

	Search				Relative Rank			
	b	SE	df	t	b	SE	df	t
(Intercept)	13.90	2.84	110.96	4.90***	2.48	0.48	123.18	5.18***
Age	1.60	6.51	100.00	0.25	1.73	1.07	100.00	1.62
Trials	-0.04	2.41	143.79	-0.02	-0.14	0.75	128.19	-0.19
NFCC	0.51	0.78	100.00	0.65	-0.07	0.13	100.00	-0.55
Age:Trials	-15.82	5.01	100.00	-3.16**	-4.70	1.64	100.00	-2.86**
Age:NFCC	-0.71	1.63	100.00	-0.44	-0.34	0.27	100.00	-1.27
Trials:NFCC	-0.04	0.60	100.00	-0.07	-0.02	0.20	100.00	-0.11
Age:Trials:NFCC	3.45	1.25	100.00	2.75**	1.05	0.41	100.00	2.56*

Note. Regression coefficient (*b*), standard error (*SE*), t value (*t*), and degrees of freedom (df) of fixed effects; $N = 104$; $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$.

Table A4

Study 1: Results of linear-mixed model for performance goals and satisfaction as a function of performance, age, and trial

	Performance goals				Satisfaction			
	b	SE	df	t	b	SE	df	t
(Intercept)	5.87	0.94	105.30	6.26***	4.347e+00	1.109e-01	123.70	39.19***
Performance	-0.02	0.02	1100.20	-1.10	-9.013e-02	6.451e-03	1219.00	-13.97***
Age	1.77	1.31	102.30	1.35	-2.443e-03	1.497e-01	103.80	-0.02
Trial	-0.06	0.05	102.00	-1.18	-1.179e-02	9.241e-03	102.10	-1.27
Age:Trial	-0.09	0.07	102.10	-1.41	-1.330e-02	1.307e-02	102.30	-1.02

Note. Regression coefficient (*b*), standard error (*SE*), t value (*t*), and degrees of freedom (df) of fixed effects; $N = 104$; *** $p < .001$.

Table A5

Study 2: Results of linear-mixed model for performance and search as a function of age, order, and task phase

	Performance				Search			
	b	SE	df	t	b	SE	df	t
(Intercept)	7.54	0.66	129.44	11.41***	12.58	1.21	169.53	10.39***
Age	1.46	0.62	122.00	2.35*	0.12	1.31	122.00	0.09
Order	-1.68	0.94	130.37	-1.79	6.08	1.71	166.39	3.56***
Task_Phase	-0.29	0.88	110.98	-0.32	1.23	1.28	95.22	0.96
Age:Order	0.69	0.88	122.00	0.79	0.66	1.85	122.00	0.36
Age:Task_Phase	1.52	0.75	122.00	2.03*	-3.07	0.94	122.00	-3.28**
Order:Task_Phase	1.10	1.59	82.00	0.69	-5.91	2.38	73.75	-2.48*
Age:Order:Task_Phase	-2.93	1.06	122.00	-2.76**	3.18	1.32	122.00	2.40*

Note. Regression coefficient (*b*), standard error (*SE*), t value (*t*), and degrees of freedom (df) of fixed effects; *N* = 126; ** *p* <.01, *** *p* <.001.

Table A6

Coefficients and t-values of LMM analyses for within task adaptations in Study 2

		Search			
		Younger Adults		Older Adults	
Condition	parameters	linear effect	quadratic effect	linear effect	quadratic effect
Short search, first phase	b (SE)	**-6.42 (1.43)**	5.79 (4.92)	**-4.33 (1.28)**	-10.78 (4.44)
	t (df)	**-4.49 (31)**	1.18 (896)	**-3.40 (76)**	-2.43(897)
	p	**8.7e-05**	.24	**.001**	.015
Short search, second phase	b (SE)	**-7.37 (1.48)**	5.21(4.67)	-2.24 (1.43)	-4.34 (4.71)
	t (df)	**-4.98 (30.7)**	1.12 (867)	-1.57 (31.8)	-0.92 (895)
	p	**2.31e-05**	.265	.126	.357
Long search, first phase	b (SE)	-4.15 (1.34)	11.28 (5.00)	1.74 (1.65)	-10.51 (4.50)
	t(df)	-3.09 (189)	2.26 (897)	1.06(31.5)	-2.34 (895)
	p	.002	.024	.297	.020
Long search, second phase	b (SE)	-0.09 (1.16)	**19.51 (4.21)**	**3.77 (0.96)**	10.29 (3.68)
	t(df)	-0.08(117.4)	**4.64 (926)**	**3.93 (744.90)**	2.80 (897)
	p	.937	**4.07e-06**	**9.14e-05**	.005
		Performance			
Condition	parameters	linear effect	quadratic effect	linear effect	quadratic effect
Short search, first phase	b (SE)	-1.97 (0.99)	5.77 (3.80)	-2.70 (1.12)	5.01 (4.11)
	t(df)	-1.99 (511)	1.52 (926)	-2.42 (30.9)	1.22 (867)
	p	.048	.129	.022	.224
Short search, second phase	b (SE)	**-3.95 (0.98)**	-2.67 (3.75)	-2.39 (0.97)	-4.30 (3.63)
	t(df)	**-4.01 (246)**	-0.71 (897)	-2.47 (32)	-1.19 (895)
	p	**7.91e-05**	.476	.019	.236
Long search, first phase	b (SE)	1.66 (0.67)	-1.77 (2.57)	-2.27 (1.01)	7.51 (3.41)
	t(df)	2.49 (861)	-0.69 (897)	-2.26 (31.8)	2.20 (895)
	p	.013	.492	.031	.028
Long search, second phase	b (SE)	0.82 (0.75)	-2.24 (2.88)	-0.01 (0.97)	-2.31 (3.69)
	t(df)	1.09 (870.3)	-0.78 (926)	-0.01 (257)	-0.63 (897)
	p	.277	.437	.989	.531

Note: Results significant at a Bonferroni corrected level (p < .002) are marked in bold.

Table A7

Study 2: Results of linear-mixed model for performance goals and satisfaction as a function of performance, age, order, and task phase

	Performance goals				Satisfaction			
	b	SE	df	t	b	SE	df	t
(Intercept)	4.68	0.76	139.90	6.16	3.28	0.12	161.10	26.08***
Performance	-0.01	-0.01	1372.00	-1.76	-0.02	0.00	1416.00	-9.56***
Age	-0.93	1.08	127.90	-0.86	0.28	0.18	150.10	1.57
Order	-1.24	1.08	128.00	-1.15	0.11	0.18	150.60	0.63
Task_Phase	0.23	0.29	1256.00	1.02	-0.09	0.07	1256.00	-1.17
Age:Order	2.60	1.52	127.80	1.70	-0.40	0.25	150.00	-1.63
Age:Task_Phase	0.23	0.33	1255.00	0.72	-0.15	0.11	1255.00	-1.32
Order:Task_Phase	-0.44	0.33	1256.00	-1.35	-0.02	0.11	1256.00	-0.22
Age:Order:Task_Phase	-0.76	0.46	1255.00	-1.65	0.26	0.16	1256.00	1.66

Note. Regression coefficient (*b*), standard error (*SE*), t value (*t*), and degrees of freedom (df) of fixed effects; $N = 126$; ** p <.01, *** p <.001.